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'IN SITU' NON-DESTRUCTIVE TESTING OF AIRCRAFT STRUCTURES BY HOLOGRAPHIC INTERFEROMETRY

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IN SITU NON-DESTRUCTIVE TESTING OF AIRCRAFT STRUCTURES BY HOLOGRAPHIC INTERFEROMETRY

by

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SUMMARY

The Report describes an investigation into a method of non-destructively testing part of an aircraft *in situ*. The method used was double-exposure holographic interferometry whereby two holograms of an object are recorded on the same holographic plate, the only difference being that the object is strained between exposures. The holograms were taken with a pulsed ruby laser and the strain applied by gentle heating.

Results indicate that the technique could be successfully applied, for example, to a complete aircraft in a hangar.

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CONTENTS

1 INTRODUCTION

Holographic interferometry[1] is a particularly useful technique for the non-destructive testing of composite structures such as CFRP (carbon-fibre reinforced plastic) and a good deal of work of this kind has previously been carried out in this Department. This work has all been done using CW (continuous wave) lasers, where necessarily long photographic exposures place restrictions on the amount of environmental vibration which can be tolerated. The practical consequence of this is that it has always been necessary to transfer the test objects to a vibrationally 'quiet' laboratory in order to carry out the work satisfactorily.

For testing large structures, such as part of a complete aircraft, this procedure would obviously be unacceptable and an 'on-site' technique would be essential. The usual method in this case is 'pulsed' holography, involving the use of a solid-state laser and an exposure which may be much less than a microsecond. In these circumstances the undesirable effects of vibration are greatly reduced and satisfactory holography is usually possible.

Pulsed holography is more difficult than CW holography and demands more elaborate equipment. For these reasons it has not until now been attempted in the Establishment. This present work is an investigation into this technique, carried out with non-specialised apparatus, with the aim of assessing the difficulties and future possibilities.

2 THE TEST OBJECT

For this work tests were conducted on part of an aircraft structure. The complete wing assembly of a P1127 (a prototype of the Harrier) was available. The centre of the wings was supported on a wooden cradle while the ends were supported by the normal landing wheels. The whole assembly stood on a concrete floor in a large hall. It was felt that this was a reasonable simulation of an aircraft in a hangar. The tests were carried out on one of the ailerons, which in this case was an aluminium skinned, honeycomb-filled structure. The advantage of using the aileron was that it could be removed and brought into the holographic laboratory for initial work.

3 THE LASER

A Laser Associates model 211C ruby laser was available and though it is not particularly suitable for this work it was felt that, provided it could be made to take holograms of objects with depth, it could be used in an attempt to do *in situ* non-destructive testing.

When a normal ruby laser is fired the light output is in the form of a short burst of rapid pulsations or 'spikes'. Apart from the large fluctuation in output, light emission in these spikes is random in phase and slightly variable in frequency. To remove these effects, which would make holography impossible, the laser was 'Q'-switched to produce a single high powered pulse with a width of about 25 nanoseconds. This very short exposure also helped to reduce the undesirable effects of vibration. For the sake of simplicity a passive dye cell 'Q'-switch was used; the cell contained a solution of chloro-aluminium phthalocyanine in pure ethyl alcohol. Though the power available per pulse was variable, it was in the order of 40 mJ. However the laser did not 'Q'-switch reliably and had to be constantly monitored to ensure that it produced only one pulse per firing. It has been suggested[2] that a more stable ouput can be obtained by aligning the laser by a method other than that recommended by the manufacturer. Briefly, the manufacturer recommends that the front and rear reflectors and the front window of the cooling water jacket are all made accurately parallel to the front face of the ruby. In the other method only the front and rear reflectors are made parallel to each other; the other surfaces, including the front face of the ruby, are deliberately mis-aligned. Both method of alignment were tried but neither one seemed to be better than the other.

To determine if the laser had sufficient temporal coherence to take in-depth holograms, the output beam was expanded and directed into a Michelson interferometer. Good contrast fringes were obtained for all path differences from zero to 40 mm, this being the limit of adjustment of the interferometer. This means that the laser has adequate coherence to take holograms of objects with depths of 80 mm and thus is suitable for use with substantially flat objects such as the surface of the aileron. No attempts were made to find the true coherence length.

The illumination produced by the laser was not uniform even after spatial filtering. A small area of reasonably uniform illumination was present and the laser beam was directed so that this area was coincident with that part of the object which was being examined.

4 EXPERIMENTAL

4.1 CW holography in the laboratory

As a first step the aileron was brought into the laboratory to determine a suitable method for straining it. Live-fringe holographic interferometry

tests were carried out using a 15 milliwatt CW helium-neon laser. Fig.1 shows the experimental layout. The light from the laser was focused by a lens L1, through a pinhole PH which acted as a spatial filter and produced even illumination. The diverging beam from the pinhole struck the beamsplitter BS where 85% was reflected onto mirror M1 to illuminate the aileron, 5% passed straight through to form the reference beam and 10% was lost by absorption and reflection from the second face of the beamsplitter. The reference beam was collimated by lens L2 and reflected by the mirror M2 onto the holographic plate. The plate was fitted in a holder which could be located accurately on a kinematic mount so that the plate would be replaced in exactly the same position after processing. All the equipment and the aileron were mounted on a vibration-free surface. The aileron was painted with matt white poster paint to produce a diffusely reflecting surface and eliminate highlights. The holograms for this and all subsequent tests were taken on Agfa-Gevaert 10E75 plates which were developed for 4 minutes in D19 diluted 1:1 with water.

As a result of live-fringe work on composite structures by other workers[3] in these laboratories it had been found that a convenient method of straining is slight heating. This also proved suitable for the aileron, the heat being applied to the front surface with a hairdryer.

As the ruby laser should only be pulsed once a minute, the live-fringe experiments provided an easy method for determining a heating cycle to be used in the pulsed holography work. It was found that a suitable pattern could be produced by applying heat to the panel for 20 seconds and then waiting 20 seconds for the hot air to disperse from in front of the aileron and for the fringes to expand to a reasonable width.

During these experiments a fringe anomaly was found in the hologram reconstruction of the aileron, which, as a later radiograph showed, was due to a reinforcing strut. It was convenient to think of this as a 'fault' in the structure and to use it as a test detail in the further work.

4.2 Pulsed holography in the laboratory

The next step was to carry out pulsed holography with the same experimental set-up and so the CW laser was replaced by the ruby laser. A spatial filter was made by focusing the laser beam onto a strip of thin metal (a razor blade) and firing the laser, un-'Q'-switched, to blast a small hole in the metal.

The purpose of this stage of the work was to demonstrate the possibility of obtaining results with the pulsed laser under ideal conditions and to confirm

that the heating cycle was suitable. Despite problems with the laser as described in section 3, it was found possible to obtain double-exposure holograms in which the reconstruction showed a fringe pattern with an anomaly due to the 'fault'.

4.3 Pulsed holography on benches

The final step in the laboratory was to remove the holographic equipment and the aileron from the vibration-free conditions and to set it up on the wooden benches which would be used in the actual job. Fig.2 shows the layout of the components. 90% of the light from the laser passed through the beamsplitter BS and was reflected by the mirror M1 onto the aileron. Some of the scattered light was reflected by the mirror M2 onto the plate. 5% of the laser light was reflected by the beamsplitter to form the reference beam. This light was collimated by lens L2 and reflected by mirror M3 onto the holographic plate. The plate was not mounted kinematically and was left uncovered between exposures. The aileron was supported by a framework of thin rods in the position which it would occupy on the wing. Double-exposure holograms were obtained which showed the 'fault'. No trouble was experienced due to the lack of rigidity of the mountings for the equipment and aileron.

4.4 Pulsed holography *in situ*

The final tests were conducted on site with the aileron mounted on the port wing. This wing was enclosed in a temporary softboard hut to make the immediate area light-tight so that the photographic plate could be left uncovered between exposures. This also had the advantage that the surrounding area did not have to be cleared for safety reasons.

The holographic equipment was set up inside the hut and arranged in the same way as in Fig.2. Fig.3 shows the laser and components set up under the wing. The sequence for taking holograms and straining the test piece was the same as before: i.e. make the first exposure, wait 20 seconds, heat the aileron for 20 seconds wait a further 20 seconds and make the second exposure.

Except for the difficulty of operating the laser reliably, it was found comparatively easy to obtain reasonable double-exposure holograms. Fig.4 is a photograph of the reconstruction from one of the better results and is similar to those obtained in the laboratory. The deviation in the vertical fringes shows the 'fault' running horizontally across the picture. (The vertical dark line in the bottom centre of the photograph is a marker on the aileron so that the position of the illumination could be determined.)

5 DISCUSSION

The scope of the work described in this paper was limited by the laser available, which had a maximum repetition rate of one pulse per minute. There are techniques of double-exposure holography in which the two exposures are separated by only a few microseconds, the strain being induced by impact[4,5]. A laser with a high repetition rate would allow one to employ these impact methods and would offer a number of advantages.

The necessity of enclosing the equipment in light-tight surroundings is obviously a disadvantage. As holographic emulsions are very slow, a technique employing a laser with a high repetition rate could be used in daylight. Either the film could be exposed to the ambient light for the fraction of a second required to take the hologram or if, due to the vibration of the shutter, the film had to be left uncovered for a longer period of time, an interference filter (or even a gelatin filter) could be placed in front of the emulsion to minimise the effect of the ambient light.

Using the present slow-repetition laser, the aircraft structure can move bodily between exposures. If this movement is large compared with that due to straining, it is possible that the resulting fringe pattern, which represents a combination of the displacements, will not show the faults clearly. (Though it was evident from the similarity of results obtained in the holographic laboratory and on site that there were no gross movements in the particular tests described in this paper.) However, with a high repetition rate laser there would be far less time between exposures for bodily movement of the test piece.

The choice of an aileron as a test piece allowed one to start with known conditions and progress step by step to unknown conditions. It is the intention, eventually, to test objects which cannot be transferred to the laboratory, so the method and amount of of straining will be unknown. Using a laser with a high repetition rate it would be easy in a short time to take several holograms, each with a different spacing between the two exposures, and thus find one which would have the required movement to give acceptable fringes.

Another disadvantage of the present laser was the small area illuminated. The laser gave about 40 mJ per pulse, sufficient to illuminate an area approximately 300mm diameter. For practical purposes an area at least a metre in diameter should be examined at any one time and this would require a laser capable of giving about 400 mJ per pulse.

Provided a high-powered pulsed laser with a high repetition rate were available, then a technique similar to that described in this Report (but using impact straining) would seem to offer a practical method of on-site non-destructive testing.

6 CONCLUSION

The results obtained show that it is possible to do *in situ* non-destructive testing of aircraft structures by pulsed double-exposure holography. However improved equipment and further work will be required before this method becomes a practical technique.

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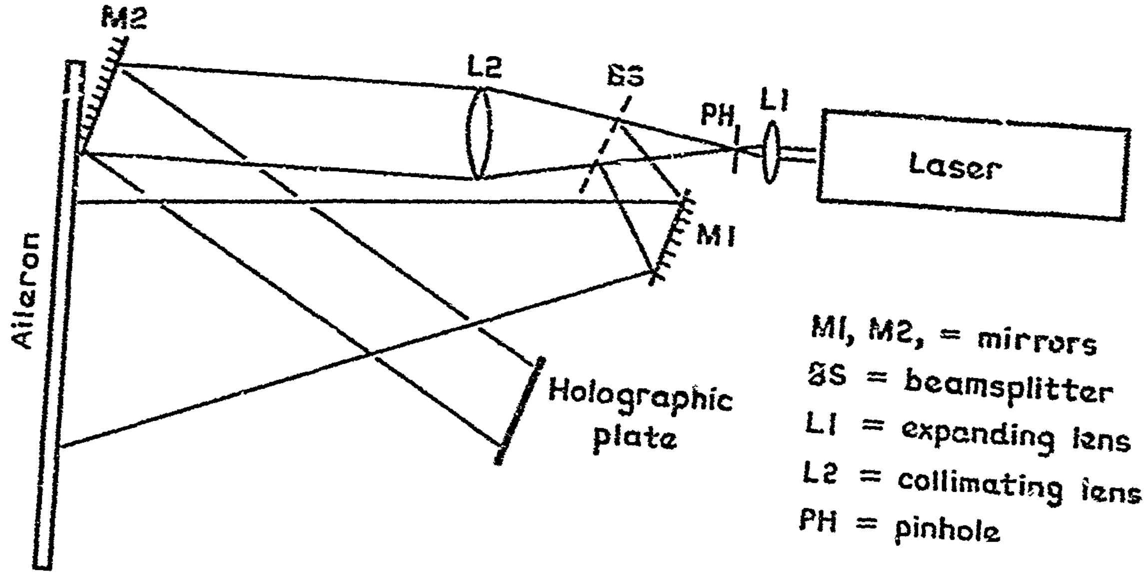

Fig. 1 Layout of optical components for live-fringe holographic interferometry

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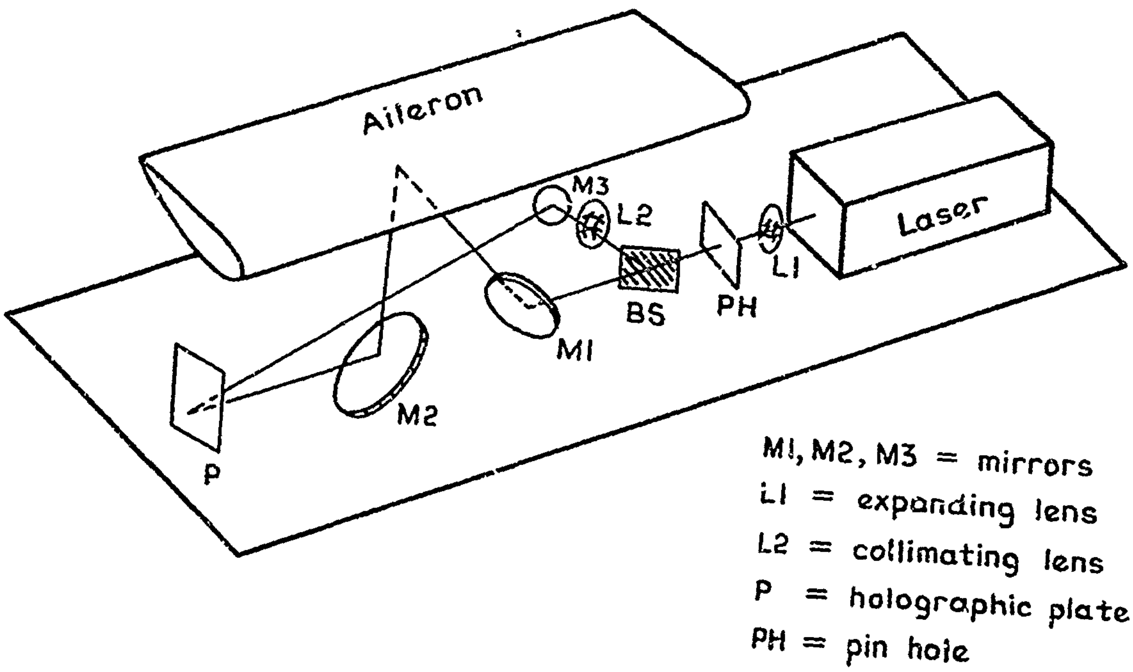

Fig. 2 Arrangement of optical components to take holograms of the aileron mounted on the wing

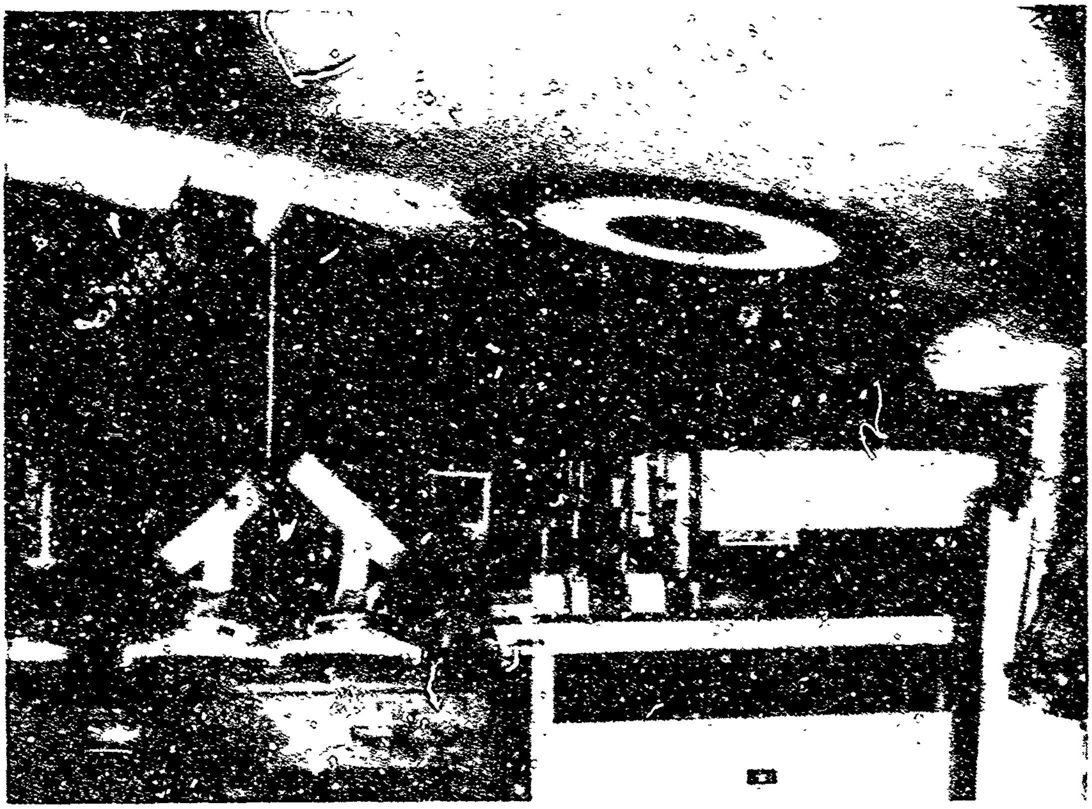

Fig.3 The laser and optical components set up under the wing

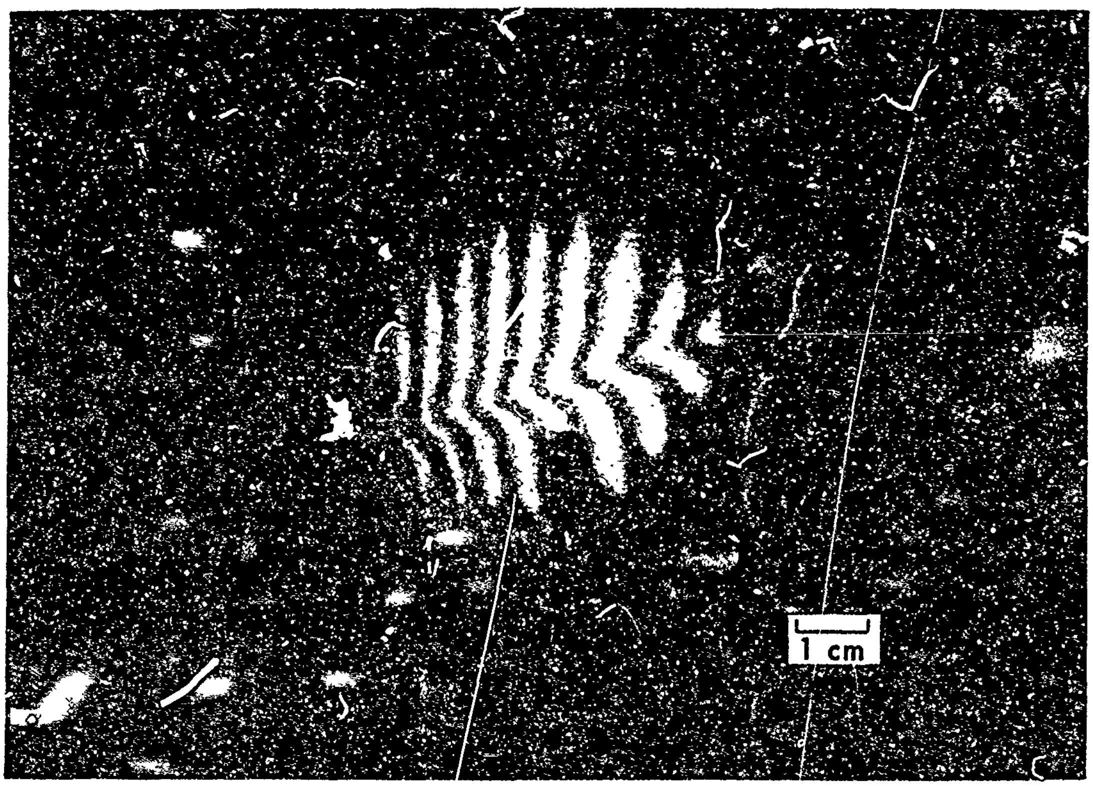

Fig.4 Reconstruction of double exposure hologram showing the 'fault'

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